Optimization Of SLL Of Rectangular Array Antennas Using Enhanced Firefly Algorithm

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Abstract: Firefly Algorithm is a stochastic and meta heuristic approach inspired from nature having a wide range of applications in solving various optimization problems. Firefly Algorithm (FA) suffers from problem of slow convergence speed. This problem can be solved by using modified Firefly algorithm called as Enhanced Firefly Algorithm. By using this algorithm side lobe level of rectangular antenna array can be reduced considerably without appreciable effect on beam width. SLL is most important array pattern parameter because reduced SLL results in minimizing received noise and interference. Low SLL in the radiation pattern of the rectangular antenna array can be achieved by considering phases and amplitudes of the excitation currents of elements of array as variables to be controlled having fixed spacing between the elements. In this paper SLL of symmetric rectangular array antenna is optimized using Enhanced Firefly algorithm (EFA) and its results are compared to the results obtained with Genetic Algorithm.

Keywords: Enhanced Firefly Algorithm, rectangular antenna array, sidelobe level, beam width, Genetic Algorithm.

1. INTRODUCTION

In many applications like radar, point-to-point links low side lobe and narrow antenna beams are required. Using random stochastic methods like Firefly Algorithm (FA) side lobe level can be reduced considerably without appreciable effect on beam width. FA based on location update process of fireflies is applied for solving difficult optimization problems. In this process attraction between one insect to the other and their moment is used for updating the location [4]. It is because of random motion of fireflies, there are chances for solution to get stuck in local minima leading to slow convergence and sometimes even failures [4]. In this paper slow convergence problem is solved by using enhanced firefly algorithm (EFA) [2]. This approach achieves faster convergence and better accuracy by using Levy Distribution Function [2]. For long distance communication, antenna array is used in place of single antenna because of their increased gain [1]. Basically, antenna arrays refer to a cluster of antennas arranged in suitable manner. The antenna array factor depends on shape of the antenna arrays (linear, rectangular etc.), inter-element spacing, amplitudes and phases of excitations of elements. Interference suppression and Side lobe reduction can be obtained by controlling these parameters. The antenna array radiation pattern is controlled by the phases and amplitudes of the excitation currents [6]. The spacing between the elements can also be controlled in order to get the optimized antenna array. The antenna array is synthesized to optimize SLL and half power beam width of the pattern. In this paper, optimization of rectangular antenna array is attempted using Enhanced Firefly Algorithm (EFA) by taking phases and amplitudes of the excitation currents as the variables to be controlled.

Antenna Arrays

A. Rectangular antenna array

Rectangular arrays, compared to their individual elements provide low side lobes, symmetrical patterns having much higher directivity [3]. They are widely used in remote sensing, tracking radars, communications etc.

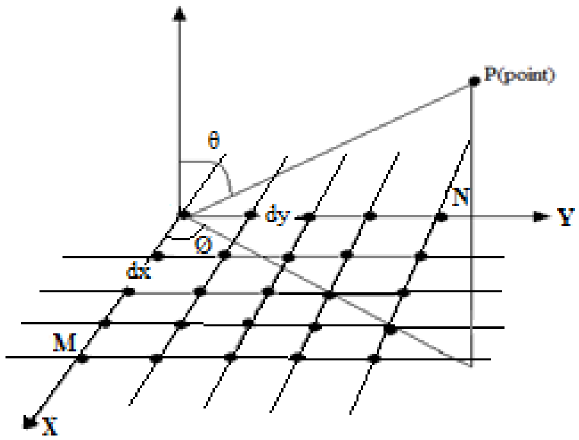

Fig.1. Rectangular Antenna Array

For a M x N element rectangular array antenna, Array Factor (AF) is given by [3]

$$AF = AF_1 \, AF_2 \tag{1}$$

$$AF_1 = \sum_{m=1}^{M} I_{m1} e^{j(m-1)(kd_x \sin\theta\cos\emptyset + \alpha_x)} \tag{2}$$

$$AF_2 = \sum_{n=1}^{N} I_{1n} e^{j(n-1)(kd_y \sin\theta\cos\emptyset + \alpha_y)} \tag{3}$$

$$I_{mn} = I_{m1} \, I_{1n} \tag{4}$$

Where AF = Array factor, AF_1= Array factor of array in x-direction, AF_2= Array factor of array in y-direction, Phase constant =k=2π/ λ, I_{mn}= current excitation of antenna element at (m, n),d_x, d_y = spacing between elements along x and y directions, Ø and θ = azimuthal and zenith angle respectively, α_x = Progressive phase shift of elements along x-axis and α_y = progressive phase shift of elements along y-axis.

B. Symmetrical rectangular array antenna

Elements of the symmetrical rectangular array antenna will be arraigned as follows

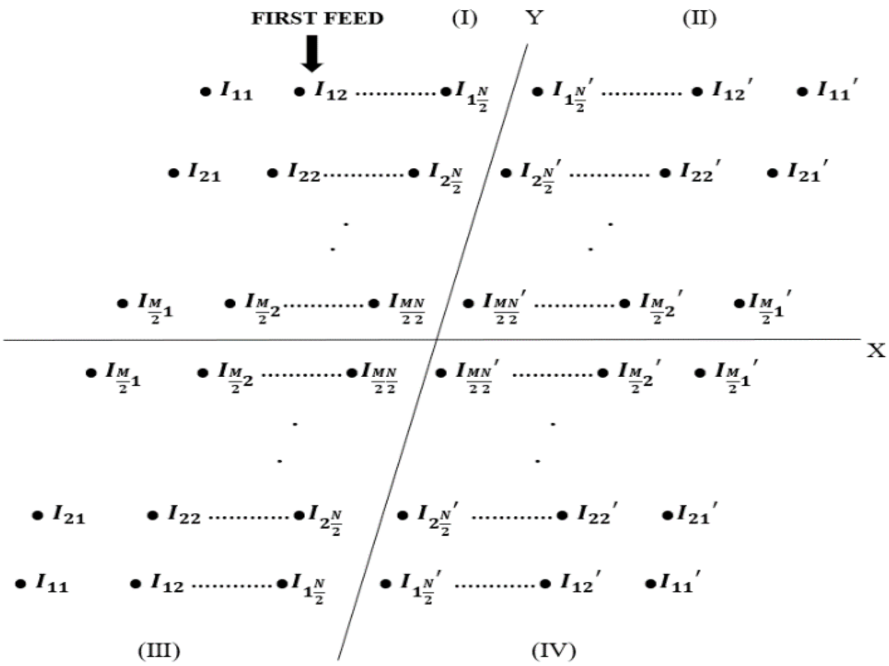

Fig.2. Symmetrical rectangular array

Amplitudes and phases of the elements of the first quadrant of XY plane will be generated randomly. The elements in second quadrant are symmetrical or mirror image to the elements in the first quadrant($I_{11} = I_{11}'$, $I_{12} = I_{12}'$ ……,$I_{\frac{M}{2}\frac{N}{2}} = I_{\frac{M}{2}\frac{N}{2}}'$). The lower half of the XY plane is the mirror image of its upper half that means all the elements of the third and fourth quadrants are symmetrical to the elements in the first and second quadrant.

For a M x N element symmetrical rectangular array antenna, Array Factor (AF) is given by

$$AF = 4\sum_{m=1}^{M/2}\sum_{n=1}^{N/2} I_{mn}\cos((m-0.5)(kd_x u+\alpha_x))\cos((n-0.5)(kd_y v+\alpha_y)) \quad (5)$$

Where u= sinθcosØ and v= sinθsinØ

Here instead of calculating array factor (AF) for M x N elements, AF is calculated only for $\frac{M}{2} \times \frac{N}{2}$ elements and it is multipled by 4. As a result, the number of computations to be performed are reduced, this leads to the increase in speed of optimization process.

Optimization Techniques

A. Genetic Algorithm (GA)

Population of GA is made up of group of individuals or chromosomes. Population of individual solutions are modified repeatedly by genetic algorithm [3]. The generated initial population is random. Parents from older generation are used for creation of next generations (children) [3]. GA uses two types of genetic operators. The first, being Crossover and the second is Mutation. Based on cost or fitness function the newly generated individuals are tested for fitness and the best of them survived for future generation. It is the genes of best individuals which are transferred throughout the population makes the newer generation better than older generation.

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B. Firefly Algorithm (FA)

FA is a search technique inspired from nature to achieve global optimization. Its application mainly focuses on optimization problems with highly non- linear and multi-modal characteristics. It takes inspiration from behaviour of fireflies and is basically an intelligence algorithm based on swarm behaviour. Fireflies have unique flashing pattern. Flashes are used to attract other fireflies for predation or mating [8]. FA depends on following assumptions (1) Attractiveness between fireflies does not depend on their sex [7]. (2) The moment always occurs from firefly with less brightness towards that of high brightness. If there are no fireflies with high brightness, the moment of a particular firefly in the space will be random [7]. (3) Objective function determines brightness of firefly. FA has many parameters that can be controlled, for example, the population size, the randomization factor, and the light absorption coefficient whose values determines the efficiency of FA [7]. For FA, selection of control parameters depends on the problem.

The two important issues related to FA are attractiveness β and light intensity variations. The brightness I of a firefly determines its attractiveness and is related to an objective function f(x) i.e., I(x)∝f(x) [9]. For a given medium, the light intensity *I(r)* is given by [9]:

$$I=I_0 e^{-\gamma r} \tag{6}$$

where γ is the absorption coefficient of light and I_0 is the original intensity of light. Due to the proportionality between light intensity and the attractiveness β of firefly, β can be written as [9]:

$$\beta=\beta_0 e^{-\gamma r^2} \tag{7}$$

where β_0 refers to attractiveness at r = 0, and the distance r between two fireflies i and j can be given by [9]:

$$r_{ij}=||x_i - x_j||=\sqrt{\sum_{k=1}^{d}(x_{i,k} - x_{j,k})^2} \tag{8}$$

where formula for position updating from non-optimal firefly i towards the best located firefly j, is given by [5]

$$x_{new}=x_i+ \beta_0 e^{-\gamma r_{i,j}^2}\left(x_j - x_i\right) + \alpha \in_i \tag{9}$$

Where the term $\beta_0 e^{-\gamma r_{i,j}^2}\left(x_j - x_i\right)$ is due to attraction, $\alpha \in_i$ is randomization and $\in_i$, α are the random number vector that are generated from uniform or Gaussian distribution and randomization parameter respectively. Here x_i and x_j are random solution, x_{new} is the obtained new solution, and γ is the absorption coefficient. For most applications β_0=1, $\alpha \in$[0,1]. By adjusting the parameters γ, α and β_0, the performance of FA can be improved [7].

C. Enhanced Firefly Algorithm (EFA)

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In various fields of research FA has been applied as it provides better results even with its basic form. Even though FA is found to work better for numerical optimization problems, the time taken to achieve global optimization increases with an increase in complication of problem, leading to increased time to obtain appropriate results [4]. This problem is a result of random moment of fireflies in different directions. The value of attractiveness in the initial phase is significantly small due to large separation between fireflies, which results in slow moment rate leading to slower convergence of FA. As FA approaches to final stage a higher value of attractiveness is obtained as the distance between the fireflies decreases [4]. In contrast to this the solution converges slowly because of their random moment resulting to a need of improvisation of FA. In this paper effort is made to design and implement updated version of basic algorithm called EFA to find optimal solutions for antenna design problems [2]. The EFA uses Levy stable distribution and hence helps in solving slow convergence problem and increases the efficiency of algorithm. In metaheuristic algorithms, random walk (representation of random steps) has a key role to play can be generated using Levy flight [10].

For EFA fireflies position updating can be achieved by [2]:

$$x_{new} = x_i + \beta_0 e^{-\gamma r_{i,j}^2}\left(x_j - x_i\right) + L(rand) \qquad (10)$$

where the term $\beta_0 e^{-\gamma r_{i,j}^2}\left(x_j - x_i\right)$ is due to the attraction and the term $L(rand)$ is randomization using Levy's flights. L represents the Levy's flight and is given by [2]:

$$L = 0.01\left(\frac{r_1\sigma}{|r_2|^{\frac{1}{\beta}}}\right) \qquad (11)$$

Here r_1 and r_2 represents random numbers where $r_1, r_2 \in [0,1]$ and $\beta=1$ and σ can be given by [2]:

$$\sigma = \left\{\frac{\Gamma(1+\beta)\sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left(\frac{1+\beta}{2}\right)\beta 2^{\left(\frac{\beta-1}{2}\right)}}\right\}^{\frac{1}{\beta}} \qquad (12)$$

Where Γ is the gamma function. Levy distribution is a special case of the inverse-gamma distribution with high stability.

Flight can be defined as the maximum distance between two points that an object in motion covers without any change in its direction [10].

The variation of attractiveness is characterized by parameter γ , whose value is of great importance in determination of convergence speed and behavior of FA. Using EFA both the local and global optima can be found simultaneously and effectively.

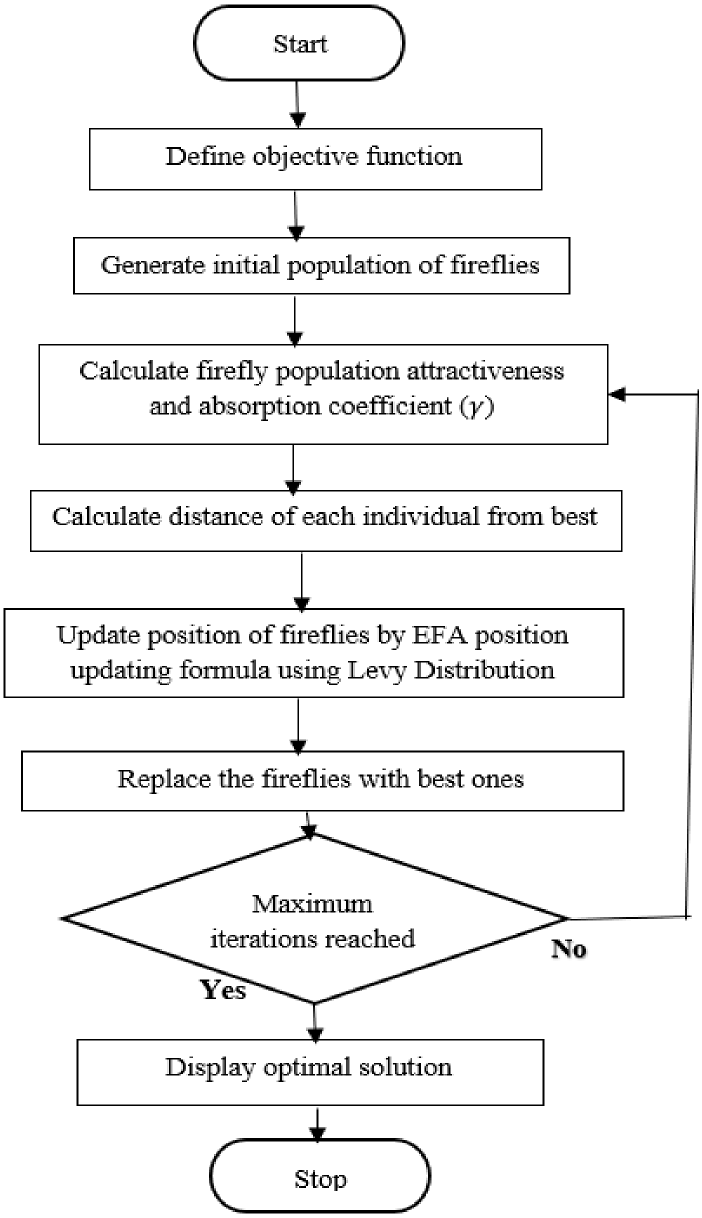

Fig.3. Flowchart of EFA

2. RESULTS AND DISCUSSION

In this paper, optimization of SLL of symmetric rectangular antenna arrays is obtained by using EFA. The amplitudes and phases of the excitations of the antenna elements are synthesized to obtain the optimized value of SLL without any appreciable effect on beam width. Comparative studies are done among results obtained with GA and EFA.
The objective function used for optimization of SLL in EFA is:

$$\text{Cost function}=\text{abs}\,(\text{SLL})-\text{abs}\,(\text{SLL}_{\text{uniform}}) \qquad (13)$$

Here abs ( ) indicates absolute value. The cost function increases with increase of iterations. MATLAB R2019a is used for simulation.
The parameters used in GA are 0.85 crossover probability and 0.01 mutation probability.
The parameters used in EFA are the attractiveness at $r = 0$ i.e., $\beta_0 = 1$ and absorption coefficient γ=1.
For both GA and EFA,

Number of flies=50, Number of rows=10, Number of columns=10 and Number of iterations=100.

The rectangular array antenna is synthesized with spacing between the elements along x and y axis is $d_x = d_y = \lambda/2$. In case of amplitude excited rectangular array antenna phase shift along x and y axis is taken as zero. In case of phase excited rectangular array antenna, current excitation of antenna element at (n, m) = $I_{mn}=1$.

The results of optimization of amplitude and phase excited 10×10 rectangular array antenna using GA and EFA are tabulated and radiation patterns are shown respectively.

Table Ⅰ: Comparison of SLL and FNBW of amplitude excited Rectangular Array Antenna

Algorithm	Number of elements (M×N)	SLL (dB)	FNBW (degrees)
GA	10×10	-30.1113	18.0
EFA	10×10	-41.5094	20.2

Table Ⅱ: Amplitude excitations of elements of first quadrant (5× 5) of 10×10 Rectangular Array Antenna

Algorithm	Amplitude excitations
GA	[1.0000,0.8655,0.5577,0.4861, 0.3994, 0.9900, 0.8765, 0.6748,0.3137, 0.3004, 0.6789, 0.6501,0.2278, 0.2847, 0.0066, 0.5868,0.1785, 0.7675, 0.0534, 0.0962, 0.0624,0.2842,0.0356, 0.1306, 0.0668]
EFA	[1.0000,0.9895,0.9797,0.5420, 0.1120, 1.0000,0.9849, 0.5879, 0.3678, 0.1872, 0.9937, 0.6111,0.3605, 0.1454, 0.1433, 0.4515, 0.4514,0.1006, 0.1000, 0.1052, 0.1373,0.2224,0.1142,0.1000, 0.1950]

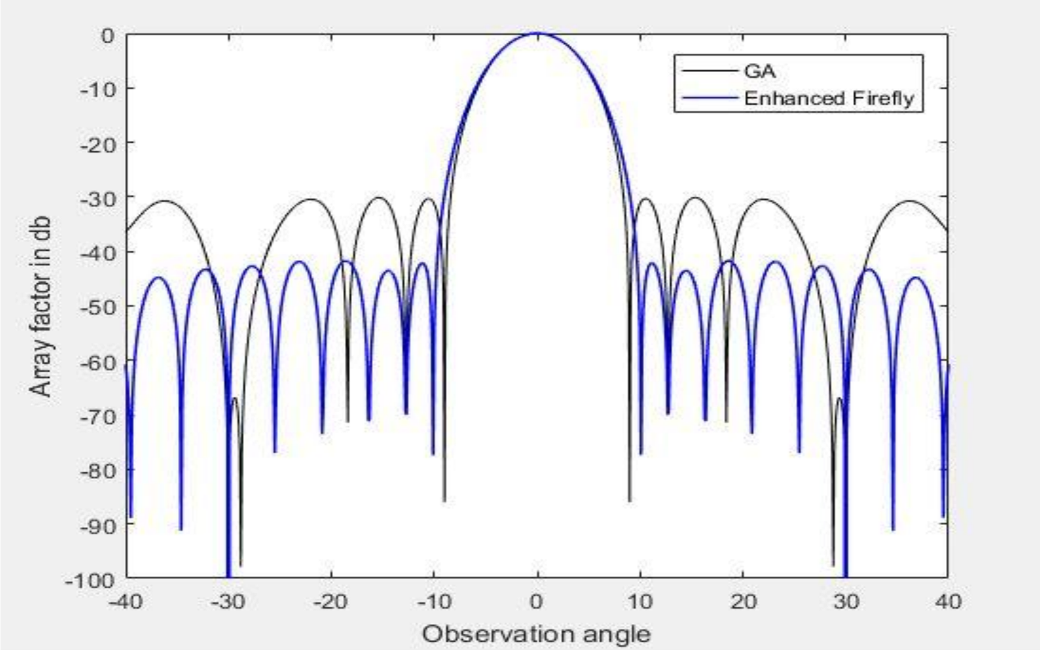

Fig.4. Pattern of radiation for amplitude excited Rectangular Array Antenna

Table Ⅲ: Comparison of SLL and FNBW of phase excited Rectangular Array Antenna

Algorithm	Number of elements (M×N)	SLL (dB)	FNBW (degrees)
GA	10×10	-16.1566	13.4
EFA	10×10	-16.6677	12.4

Table Ⅳ: Phase excitations of elements of first quadrant (5× 5) of 10×10 Rectangular Array Antenna

Algorithm	phase excitations
GA	[0, 3, -8, 20, 20, 4, 5, 9, 1, 6, 1, -16, 19, 1, -18, 3, 1, 20, 1, 20, -5, 7, -19, 20, -9]
EFA	[0, -10, -7, 12, 20, -9, 7, -9, 18, 20, -10, -10, -10, 19, 20, -8, -10, 2, 20,20, -3, -10, -10, 19, 20]

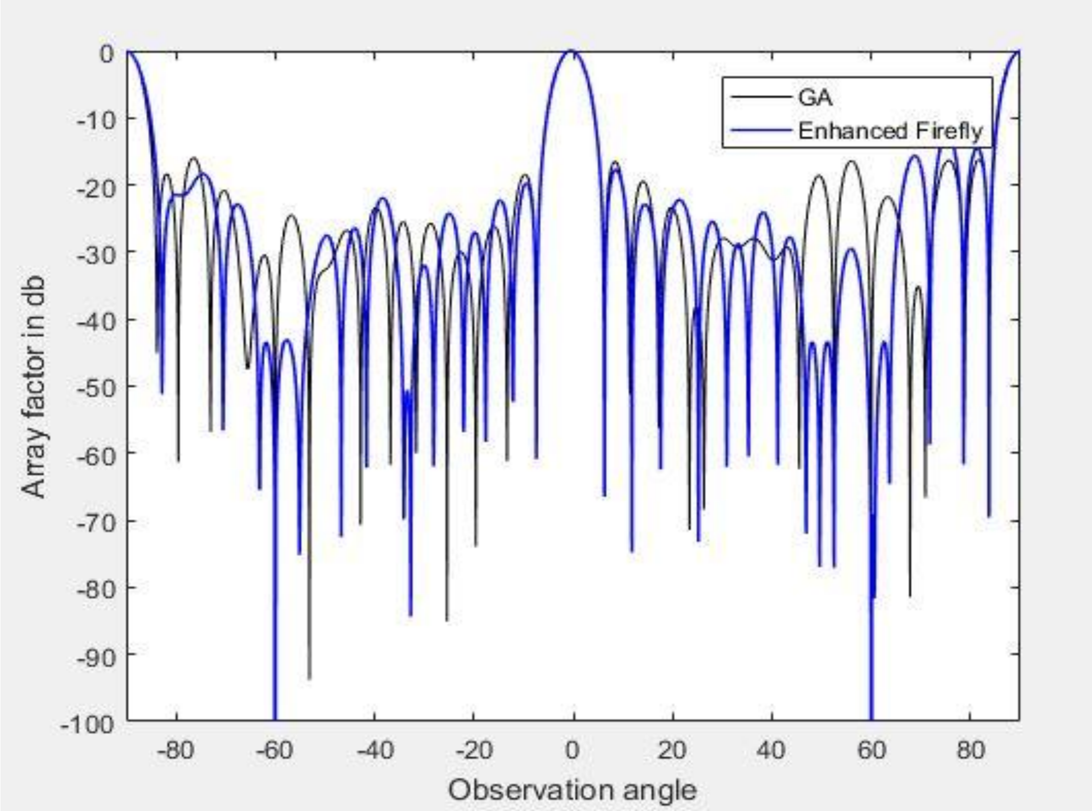

Fig.5. Pattern of radiation for phase excited Rectangular Array Antenna

3. CONCLUSIONS AND FUTURE SCOPE

It is found that EFA provides much better optimization of SLL without appreciable effect on beam width when compared to GA. From the results, it is evident that the best values of SLL are obtained for random amplitude excitations when compared to random phase excitations of the antenna elements in rectangular array antennas. For amplitude excited rectangular array antenna, SLL is reduced to -41.5094 dB and FNBW of 20.2 degrees is obtained by using EFA. In case of phase excited rectangular array antenna, the best SLL of -16.6677 dB and FNBW of 12.4 degrees is obtained by using EFA. Further extension of this work can be done by optimization of SLL using other random stochastic techniques.

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